Diagnosing Areal Density using the Magnetic Recoil Spectrometer (MRS) at OMEGA and the NIF

The MRS on OMEGA

Cryogenic DT  \( Y_n \approx 5.8 \times 10^{12} \)

Deuteron Energy [MeV]

Counts / MeV

136 mg/cm²

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Abstract

A Magnetic Recoil Spectrometer (MRS) has been installed and activated on OMEGA for measurements of down-scattered and primary neutrons, from which areal density, ion temperature, and yield of cryogenic DT implosions can be inferred. To correctly interpret these measurements, the MRS response function was characterized using the Monte Carlo code GEANT4 and diagnostic activation experiments. The results of the MRS characterization as well as measurements of the absolute neutron spectrum at OMEGA will be presented.

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Motivation for the MRS at OMEGA

• Measure the absolute neutron spectrum of cryogenic DT implosions

• Infer $\rho R$ from the down-scattered neutron spectrum

• Measure absolute neutron yield

• Determine fuel ion temperature from Doppler broadened primary neutron spectrum and characterize non-thermal features, if present
The neutron spectrum contains a wealth of information including the $\rho R$, $T_i$, $T_e$, and $Y_n$

**From down-scattered ($Y_{ds}$):**
- $\rho R \propto \frac{Y_{ds}}{Y_{1n}}$

**From primaries ($Y_{1n}$):**
- $Y_{1n}$
- $T_i \propto \Delta E^2$

**From Secondaries ($Y_{2n}$):**
- $T_e \propto \frac{Y_{2n}}{Y_{1n}}$

**From Tertiaries ($Y_{3n}$):**
- $\rho R \propto \frac{Y_{3n}}{Y_{1n}}$
The principle of the Magnetic Recoil Spectrometer (MRS)

CH-foil or CD-foil

Magnet

Entrance

Exit

10 cm (Ω)
26 cm (NIF)

215 cm (Ω)
570 cm (NIF)

Magnet housing

Detector housing

CR-39

6-28 MeV (p)
3-14 MeV (d)

MRS detection efficiency and energy resolution

- The detection efficiency is defined as:

\[ \varepsilon_{MRS} = \frac{\Omega_n \cdot n_i \cdot t}{4\pi} \int_{\Omega_r} \frac{d\sigma}{d\Omega_{lab}} d\Omega \]

Absolute yields are measured since \( \Omega_n, n_i, t, \frac{d\sigma}{d\Omega} \), and \( \Omega_r \) are known.

- Resolution \((\Delta E_l)\) is defined as:

\[ \Delta E_l = \sqrt{\Delta E_f^2 + \Delta E_k^2 + \Delta E_m^2} \]

\( \Delta E_f = \) Energy loss in foil \( \propto \) foil thickness
\( \Delta E_k = \) Kinematic energy broadening \( \propto \) foil and aperture sizes
\( \Delta E_m = \) Optical energy broadening \( \propto \) magnet performance
The 1st phase of the MRS installation was completed in September 2007

Pictures by Eugene Kowaluk
During the 2nd installation phase, polyethylene neutron shielding was installed around the MRS in Spring 2008

~2000 lbs of polyethylene shielding installed around the MRS

Pictures by Eugene Kowaluk
The Monte Carlo code Geant4 is being used to model the full MRS detector response.
Areal density ($\rho R$) can also be inferred from knock-on protons (KO-p), and knock-on deuterons (KO-d).

$$S \propto \rho R \times Y_n$$

$$B \propto Y_n$$
KO-p and KO-d measurements are made with magnet based charged particle spectrometers like CPS or the MRS without a foil.
The OMEGA MRS obtained KO-d** data on a cryogenic DT implosion after shielding was installed.

Shot 50515  \((Y_n = 2.3 \times 10^{11})\)

No data from CPS1; sensitivity too low

**J. A. Frenje et al., LLE Progress Report for DOE (Jan 2008).
The Coincidence Counting Technique (CCT) is used to reduce the background for DS-n measurements.

Applying the CCT can enhance the S/B by orders of magnitude in low yield measurements.
TT fusion neutrons overlap the lower part of the down-scattered neutron spectrum

Primary TT Neutrons

- $T + T \rightarrow \alpha + n + n$
- $T + T \rightarrow \alpha + 2n$
- $T + T \rightarrow ^{*}He{^5} + n$

Cryo DT Neutron spectrum for \(\rho R \sim 150\text{mg/cm}^2\ T_i \sim 2.5\text{keV}\)

For a \(\sim 150\text{mg/cm}^2\) cryogenic DT neutron spectrum the TT contribution in the MRS down-scattered measurements is \(\sim 12\%\)*

*This is for a low resolution measurement of the down-scattered neutron spectrum*
The TT contribution to the neutron spectrum is calculated using the reactivity ratio for a given $T_{\text{ion}}$

\[
Y_{TT} / Y_{DT} \approx \frac{1}{2} \frac{n_T}{n_D} \frac{<\sigma v>_{TT}}{<\sigma v>_{DT}}
\]

This assumes approximately equal DT and TT spatial and temporal burn profiles.
The first DS-n measurements were performed using warm CH DT implosion in April and May 2008.

Shots 51294-51298 – $\rho R_{\text{shell}} = 45 \text{mg/cm}^2 \pm 20 \text{mg/cm}^2$

Shots 51316-51320 – $\rho R_{\text{shell}} = 65 \pm 23 \text{mg/cm}^2$

Best fit neutron spectrum

Counts / MeV

Deuteron Energy [MeV]

MRS Data

Fit

Counts / MeV

Neutron Spectrum [1/MeV]

Energy [MeV]

Deuteron Energy [MeV]

Energy [MeV]
An areal density of $136 \pm 23 \, \text{mg/cm}^2$ was inferred from the first down-scattered neutron measurement of a cryogenic DT implosion.
Summary

The first MRS measurements at OMEGA show the diagnostic is performing well

► The MRS was installed on OMEGA in summer 2007 and the neutron shielding installed in spring 2008

► The MRS response function is being characterized using Geant4 and implosions producing DHe\(^3\) protons and primary DT neutrons

► The CCT was developed to dramatically reduce the background (~10-100 times) for down-scattered neutron measurements for the OMEGA MRS

► The first down-scattered neutron measurements of non-cryogenic and cryogenic DT implosions have been successfully performed
Some Important References


